II.2 10-kW Solid Oxide Fuel Cell Power System Commercialization

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Subcontractors: SOFCo, Alliance, Ohio

Objectives

- The objective of this Cummins Power Generation (CPG) and SOFCo-EFS Holdings LLC (SOFCo) project is to demonstrate the Solid State Energy Conversion Alliance (SECA) Phase 1 solid oxide fuel cell (SOFC) objectives through technical progress in the following areas:
- SOFC stacks that achieve target performance and stability and that can be manufactured in volume at the target cost.
- A waterless catalytic partial oxidation (CPOX) reforming process that can efficiently and cost effectively convert natural gas or propane into a hydrogen-rich synthesis gas.
- SOFC hot box subsystem design (insulated enclosure containing SOFC stacks, manifolds, heat exchangers, start-up burner, and reformer) that is compact and can be mass-produced at a cost meeting the Phase 1 cost target.
- SOFC system balance of plant, including air and fuel supply systems, that meets the cost and reliability targets.
- A control system for the SOFC power system, including regulation of fuel and air flows and management of electrical power generation and load sharing. Control system must function in conjunction with an energy storage system through start-up, steady-state and transient loads, and shut-down, including emergency shut-down without damage to the SOFC stack.
- An efficient electrical power conditioning system to convert DC voltages and invert them to produce useable AC output.

Approach

The CPG-SOFCo approach coordinates development in the following major areas:

- Planar SOFC cell, interconnect, and stacks
- Planar SOFC manufacturing and scale-up
- Dry CPOX fuel reforming
- Fuel cell balance-of-plant (BOP)
- Fuel cell and power electronics system controls
- Power conditioning

Specifically, the CPG-SOFCo team is conducting the following work:

- Develop and evaluate advanced solid oxide fuel cells that provide the required performance and are compatible with the SOFCo ceramic interconnect.
- Use a progression of stack tests to validate the development of materials and assembly methods for useable stacks that can achieve high fuel utilization (good sealing) and low degradation rates.
- Develop a CPOX reforming process and scale-up to system-sized units.
- Design and develop a hot box subsystem which can be delivered to CPG for integration into complete SOFC power systems.
- Develop control hardware and software required to regulate system operation.
- Integrate the BOP components, hot box subsystem, and controls into a working development prototype. Operate the prototype with stack simulators to shake down the system, followed by installation of SOFC stacks and operation of the full prototype.
- Evaluate and refine the lessons learned from the prototype system to design, construct, and test the deliverable SECA Phase 1 system.

Accomplishments

- Advanced electrolyte-supported cells demonstrated improved cell performance. These cells meet the interim performance targets defined for Phase 1 of the SECA project.
- Degradation of short stacks was reduced to <4% per 500 hours. Fuel utilization in excess of 80% with natural gas reformate was demonstrated. These results confirmed the viability of SOFCo's stack assembly method, the materials used for seals, and electrical contacts between the cells and interconnects.
- Dry (waterless) CPOX reforming for natural gas and propane were successfully demonstrated. The bench-scale CPOX reactor was scaled up for use in a kilowatt-scale prototype system. Long-term testing with natural gas showed stable operation for more than 2500 hours, and stacks operated on the reformate demonstrated no problems through 2000 hours of testing.
- A kilowatt-scale prototype hot box was constructed incorporating two stack simulators. The hot box subsystem was successfully integrated with the BOP components in the test facility at CPG.
- The kilowatt-scale C1 prototype has been operated successfully on reformed pipeline natural gas. Testing on the C1 prototype validated system models and control algorithms and provided valuable information on system transient response.

Future Directions

- Refine the composition and microstructure of the electrodes for the advanced electrolyte-supported cell as required to achieve the Phase 1 target performance.
- Use instrumented short stacks and continued optimization of materials to assemble stacks that further reduce the non-cell contributions to resistance and power degradation rates.
- Complete the design and development of a robust tall stack assembly for the system prototype to be delivered to DOE at the end of Phase 1.
- Scale the CPOX reformer to 6 kWe and complete testing using natural gas. Testing will be used to establish operating parameters and control requirements.
- Complete the design and construction of the deliverable hot box subsystem. Assemble the hot box and deliver to CPG.
- Complete the specification and procurement of the balance of plant for the deliverable system.
- Complete the final tailoring and development of the DC converters for the fuel cell and battery system.
- Complete the development and integration of the control system with the fuel cell, balance of plant, and power electronics.

Introduction

Solid oxide fuel cell power systems offer the potential to generate electrical power from hydrogen or hydrocarbon fuels cleanly and efficiently. The objective of the CPG-SOFCo project is to design and develop a 3-10 kW SOFC-based power system that can be competitive with existing small diesel generating systems in terms of cost and package size, but offer significant benefits in efficiency, emissions, lower noise and vibration. Achieving these objectives requires advancement in five major areas:

- Cell, interconnect, and SOFC stack performance and robustness
- Optimizing manufacturing processes for production of cells, interconnects, and stack assemblies
- System design, thermal integration, and packaging of the hot components and sub-systems including stacks, fuel reformer, heat exchangers, and insulation system
- Control system for regulating air and fuel flows to the stacks in proportion to electrical load and operating temperatures, and for managing electrical load distribution between the fuel cell and batteries during steady-state and transient loading
- Electrical power conditioning, including DC voltage boosts (converters) and DC to AC power (inverter)

The team has made significant progress in all five areas during 2004 and is on plan to meet the objectives of Phase 1 of the SECA project.

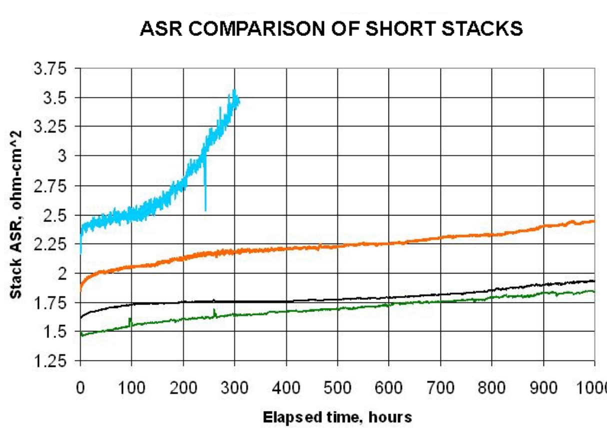

Figure 1. Improved Performance of SOFC Stacks

Results

Development work during 2004 has substantially improved cell performance, primarily through the introduction of scandia-stabilized zirconia electrolytes to improve ionic conductivity and reduce cell area specific resistance (ASR). Through this work, ASRs have been reduced by a factor of three and are approaching the Phase 1 target value. [Figure 1.]

Typical stack power degradation at constant voltage has been improved to 3% per 500 hours, nearing the Phase 1 target of 2% per 500 hours. [Figure 2.]

Dry (waterless) CPOX reforming for natural gas and propane (LP gas) were successfully demonstrated. The bench-scale CPOX reactor was scaled up for use in a kilowatt-scale prototype system. Long-term testing with natural gas showed stable operation for more than 2500 hours, and stacks operated on the reformate demonstrated no problems through 2000 hours of testing. [Figure 3.]

A progression of stack tests at 5 cells, 20 cells, and 47 cells, respectively, has validated the stack assembly process and the integrity of the stack sealing system. Target fuel utilization of 80% has been demonstrated on stacks of all sizes.

Design and manufacturing work to scale up the ceramic interconnect from approximately 10 by 10 cm to 15 by 15 cm is on track to produce high-quality parts meeting design requirements.

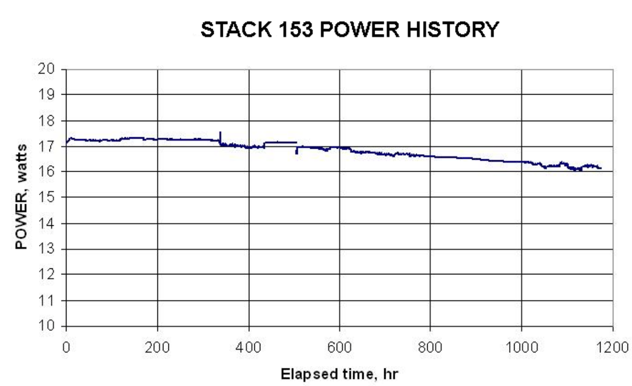

Figure 2. Improved Degradation Performance of SOFC Stacks; Calculated Average Degradation 2.9% per 500 Hours

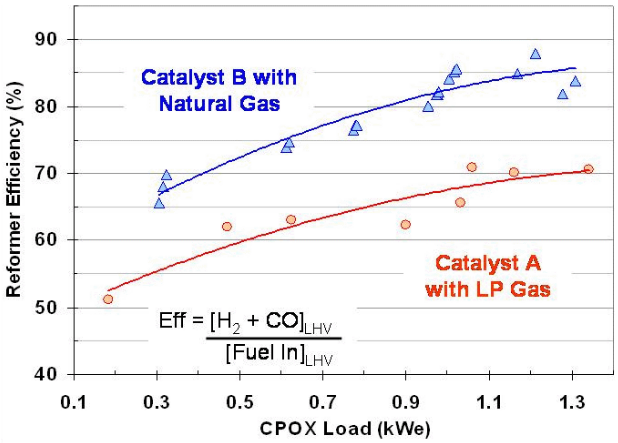

Figure 3. High-Efficiency CPOX Operation on Natural Gas and Liquefied Petroleum (LP) Gas

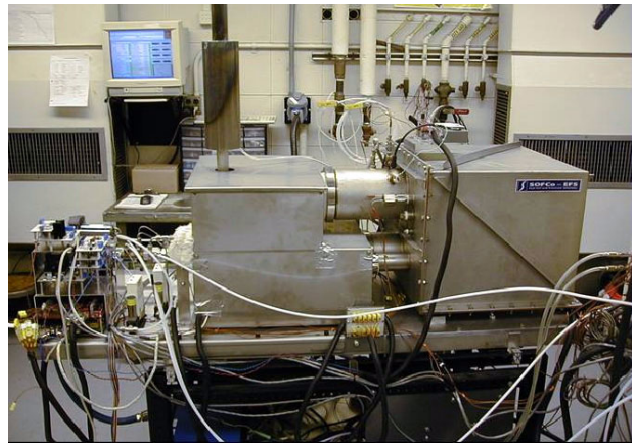

Figure 4. kW-Scale SOFC Development Prototype System

Testing of a kW-scale demonstrator unit at CPG in Minneapolis has provided valuable information validating system modeling and control strategy. During testing, CPG-developed controls exhibited excellent steady-state and transient stability and response.

CPG demonstrated a high-efficiency DC-DC boost system which will be used to control current flow and voltage supply to the inverter section from the fuel cell stacks and from the batteries. [Figure 4.]

Conclusions

- Electrolyte-supported cells with ScSz electrolytes provide improved SOFC performance.
- Planar SOFC stacks in the range of 50 repeat units can be constructed and successfully operated at high fuel utilizations.
- A dry (waterless) catalytic partial oxidation reformer system can provide a suitable fuel stream from commercial natural gas without sulfur removal and without forming carbon.
- A compact kilowatt-scale SOFC power system can be started and operated within design parameters in both steady-state and transient operating modes.
- DC-DC voltage conversion can be accomplished at high (98%) efficiency with simple, producible, and cost effective inductor-based DC-DC boost.

FY 2004 Publications/Presentations

1. R. Goettler, T. Cable, K. Kneidel, T. Morris and E. Barringer, "SOFCo Planar Solid Oxide Fuel Cell Development Status," 2003 Fuel Cell Seminar Abstracts, pp. 902-905, November 2003.

2. L. Xue, E. Barringer, T. Cable, R. Goettler and K. Kneidel, "SOFCo Planar Solid Oxide Fuel Cell," International Journal of Applied Ceramic Technology, Volume 1, Number 1, pp. 16-23, February 2004.

3. D. Norrick, "10kWe SOFC Power System Commercialization Program Progress," SECA Annual Workshop, May 11, 2004, Boston, MA.